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HARMONIC CURRENTS FROM INDUSTRIAL BATTERY CHARGERS ADDENDUM

Report No 90-324-K

G.K. Hatanaka
Research Engineer
System Studies Section
Electrical Research Department

ABSTRACT

Research Report No. 90-47-H describes the results of harmonic measurements performed on four types of three-phase industrial battery chargers. Additional measurements have been performed on chargers from four different manufacturers. The results support the earlier findings. The harmonic distortion of the input ac current depends on the type design. The eight chargers tested represent four basic designs. The Ferroresonant charger exhibits superior harmonic performance to the others.

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To: Mr. J.E. Mitchell
Manager
Technical Services & Development
Program Support & Services Division

HARMONIC CURRENTS FROM INDUSTRIAL BATTERY CHARGERS
ADDENDUM

G.K. Hatanaka

1. *Introduction*

Harmonic measurements were made on industrial battery chargers from four different manufacturers. These tests supplement those detailed in Research Report No. 90-47-H [1]. This report has been prepared as an addendum to the earlier report. Reference should be made to that report for the terms of reference, test procedures and a review on harmonic analysis.

2. *Research Report No. 90-47-H*

Table I given in Report No. 90-47-H summarizes the results of the earlier measurements on four different design types.

Figures 1 to 4 given in Report No. 90-47-H show the current and voltage waveforms in the time domain and the corresponding harmonic content in the frequency domain under each of the test conditions. Tables 1 to 4 give the harmonic magnitudes and phase angles.

Appendix A briefly describes the relationship between some typical waveforms and their harmonic content as a guide to understanding the test results.

3. *Summary of Supplementary Test Results*

Additional harmonic measurements were performed on industrial battery chargers from four different manufacturers, each connected in turn to a three-phase 600 V supply (1000 kV A, 27,600 V/600 V, 5.8% impedance, Δ-Y transformer). This supply was different than that used in the earlier tests. Otherwise the test procedure was the same.

The tests are not meant to compare the harmonic performance of the different products. Therefore, the manufacturers' make and models are not given.

Tables and Figures in this report have been numbered consecutively from those in Report No. 90-47-H for convenience.

Table II below summarizes the results of the additional tests on chargers from four different manufacturers. The results of earlier tests have been included for comparison. Figures 5 to 8 show the current and voltage waveforms in the time domain and the corresponding harmonic content in the frequency domain under different charging conditions. Tables 5 to 8 give the harmonic magnitudes and phase angles.

Table II Summary of Harmonic Measurements on Battery Chargers from 8 Different Manufacturers

Test Condition			Current (I_r)				Voltage (V_{r-w})		
Charger No.	Charger Type	Rate of Charge	60 Hz rms A	Composite rms A	THD %	Harmonics rms A	60 Hz rms V	Composite rms V	THD %
No. 1	SCR (Half-Controlled Rectifier)	Maximum	13.85	16.54	65.2	9.03	586.02	586.17	2.2
		Minimum	5.20	6.49	74.9	3.9	585.04	585.19	2.3
		Ambient	na	na	na	na	587.47	587.61	2.1
No. 2	Magnetic Amplifier	Maximum	8.33	8.94	38.7	3.22	585.48	585.58	1.8
		Minimum	4.80	5.05	32.6	1.56	590.52	590.66	2.2
		Ambient	na	na	na	na	586.35	586.45	1.9
No. 3	Ferro-Resonant	Maximum	10.82	10.84	6.3	0.68	582.14	582.25	1.9
		Minimum	3.62	3.63	7.5	0.27	568.72	568.80	1.8
		Ambient	na	na	na	na	584.07	584.18	1.9
No. 4	High Frequency (Full-Wave Rectifier/ Inverter)	Maximum	7.86	8.18	29.1	2.29	561.86	561.93	1.6
		Minimum	2.68	2.81	31.3	0.84	568.39	568.47	1.7
		Ambient	na	na	na	na	565.05	565.10	1.4
No. 5	Magnetic Amplifier	Maximum	8.29	8.52	23.7	1.96	587.27	587.86	2.2
		Minimum	3.37	3.41	15.7	0.53	594.00	594.16	2.3
		Ambient	na	na	na	na	587.08	587.25	2.4
No. 6	Ferro-Resonant	Maximum	10.65	10.67	6.7	0.71	589.45	589.66	2.7
		Minimum	3.07	3.08	6.6	0.20	588.55	588.69	2.1
		Ambient	na	na	na	na	589.46	589.61	2.3
No. 7	Ferro-Resonant	Maximum	12.10	12.11	4.6	0.56	586.83	587.04	2.7
		Minimum	2.06	2.07	12.4	0.26	588.79	588.91	2.0
		Ambient	na	na	na	na	586.59	586.80	2.7
No. 8	Magnetic Amplifier	Maximum	7.57	7.98	33.0	2.50	590.28	590.46	2.5
		Minimum	3.25	3.44	34.0	1.11	589.79	589.90	2.0
		Ambient	na	na	na	na	591.79	591.99	2.6

Note: Results are for an FFT performed on a time captured waveform, up to the 21st harmonic, using a flat-top window. The results for Chargers Nos. 1-4 have been reproduced for convenience from Table I in Research Report 90-47-H. Charger No. 2 was incorrectly identified in the earlier report and is properly classified here as a Magnetic Amplifier.

4. *Conclusions*

Harmonic analysis was performed on industrial, three-phase battery chargers from four different manufacturers. The results supplement those given in Research Report No. 90-47-H on four other chargers. The eight chargers represent four basic design types:

- Controlled Rectifier (Half-controlled Bridge)
- Magnetic Amplifier (also known as Saturable Reactor)
- Ferroresonant
- High Frequency (Full-wave Rectifier/Inverter)

The following conclusions are based on all the test results.

4.1 ***The voltage distortion is not a good indicator of the harmonic performance of battery chargers.*** The harmonic distortion of the voltage waveform is a function of the ac supply impedance and the harmonic conditions. Under the given test conditions, the voltage distortion resulting from the harmonic current injection from the chargers did not increase significantly above the existing ambient levels of voltage distortion.

4.2 ***The current distortion is a good indicator of the harmonic performance of battery chargers.*** However, when the distortion is given as a percent (THD%), it is essential that it be given together with the base current (the RMS 60 Hz load current). The impact of the harmonic distortion is related to the RMS value of the harmonic current injected into the supply.

4.3 ***The harmonic performance of the battery chargers depends on the type of design.*** The ferroresonant charger is clearly superior to other design types in terms of harmonic performance. The resonant circuit used for voltage regulation acts as a harmonic filter and buffers the input from the rectifier circuit. The other types show similar performance to one another because the incoming ac current is switched or rectified. The half-controlled (control on only one half-cycle) rectifier exhibits inferior harmonic performance. It generates an unsymmetrical input ac current waveform that results in substantial even harmonics. A fully controlled (controlled on both half-cycles) rectifier would restore waveform symmetry and eliminate the even harmonics resulting in performance similar to the magnetic amplifier and high frequency types of chargers.

5. *Recommendations*

There are no standards or benchmarks that can be used to accept or reject products based on harmonic performance. Nevertheless, the test results can be used to make informed decisions on the selection and application of industrial battery chargers in order to minimize the impact of the injected harmonic currents on other equipment and on the quality of the utility supply system. Good judgement may also avoid the need to install additional mitigative equipment to resolve problems.

6. *Acknowledgements*

I wish to thank Mr. C. Keyes and his staff in the Utilization Section of the Electrical Research Department for their cooperation and Mr. B. Pietrantonio for his fine work in performing the harmonic measurements and reducing the data.

Approved:

A.F. Baljet
Manager
Electrical Research Department

Submitted:

G.K. Hatanaka
Research Engineer
System Studies Section

GKH:am

References

1. G.K. Hatanaka, "Harmonic Currents From Industrial Battery Chargers," Ontario Hydro Research Report No. 90-47-H.

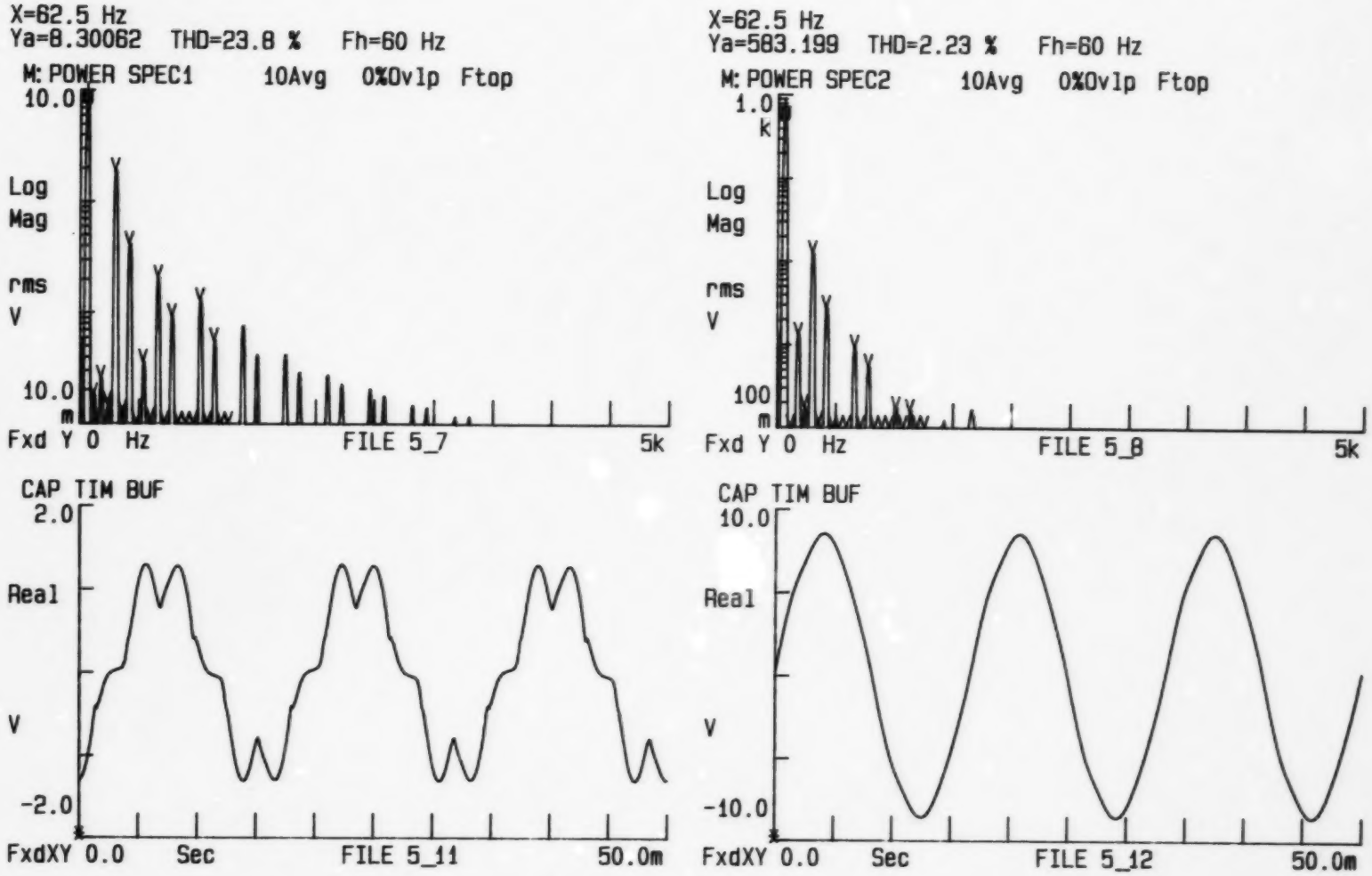

Figure 5 a) ***Battery Charger No. 5, Magnetic Amplifier Under Maximum Charging Rate.***

i) ***Top Left - Current Harmonics***
Bottom Left - Current Waveform

$I_{60\ Hz}$ = 8.3 A rms, THD = 23.8%

ii) ***Top Right - Voltage Harmonics***
Bottom Right - Voltage Waveform

$V_{60\ Hz}$ = 583.2 V rms, THD = 2.2%

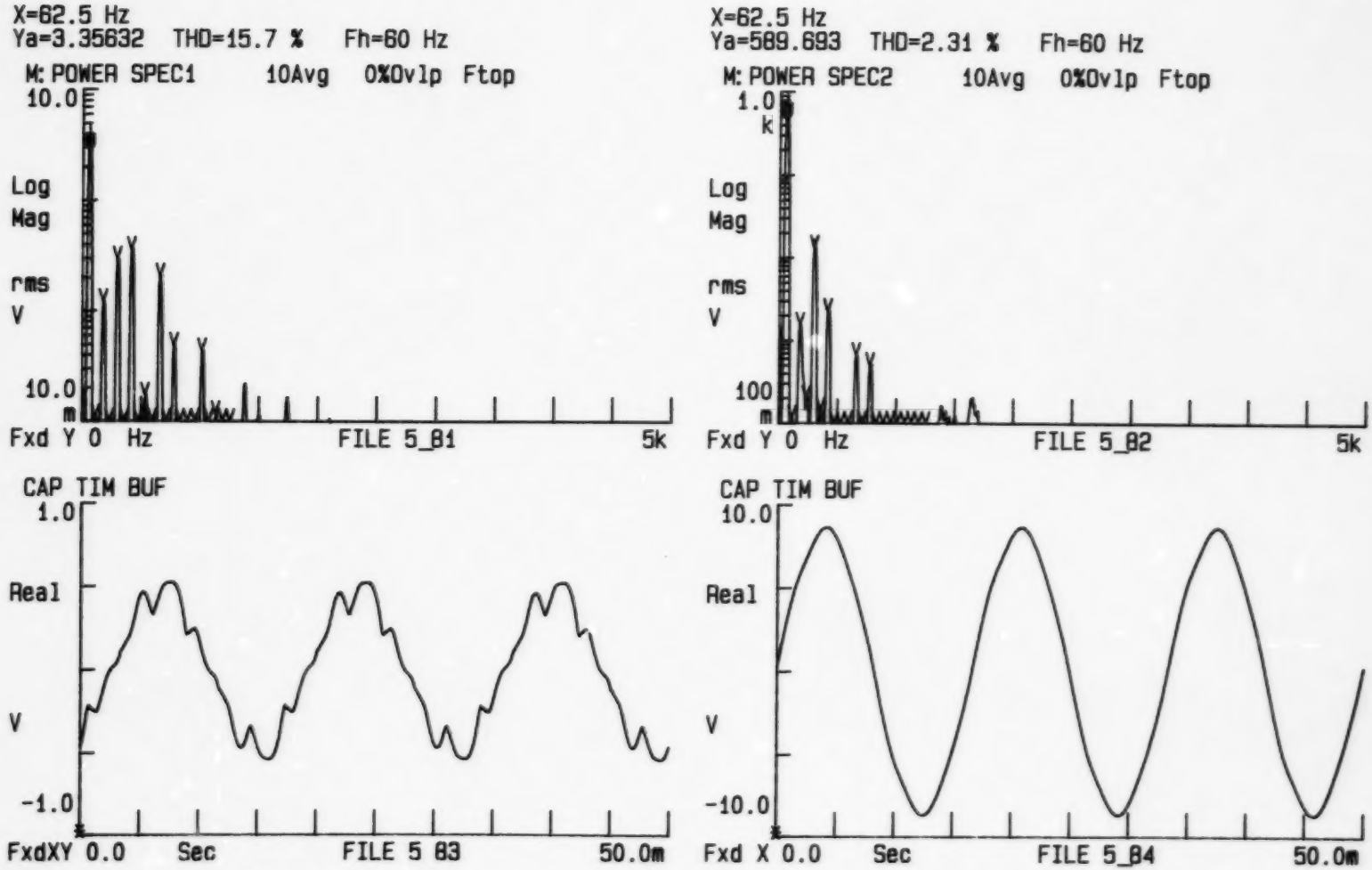

Figure 5 b) ***Battery Charger No. 5, Magnetic Amplifier Under Minimum Charging Rate.***

i) ***Top Left - Current Harmonics***
Bottom Left - Current Waveform

$I_{60\ Hz}$ = 3.4 A rms, THD = 15.7%

ii) ***Top Right - Voltage Harmonics***
Bottom Right - Voltage Waveform

$V_{60\ Hz}$ = 589.7 V rms, THD = 2.3%

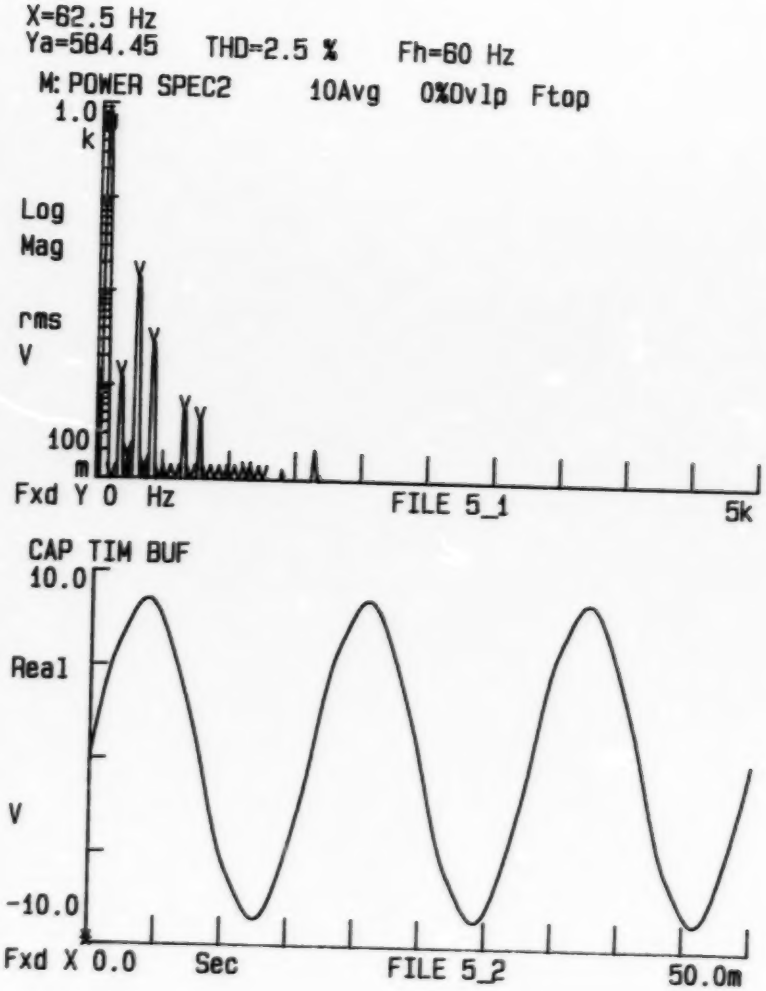

Figure 5 c) ***Battery Charger No. 5, Magnetic Amplifier Ambient Voltage Conditions.***

Top - Voltage Harmonics
Bottom - Voltage Waveform

$V_{60\ Hz}$ = 584.5 V rms, THD = 2.5%

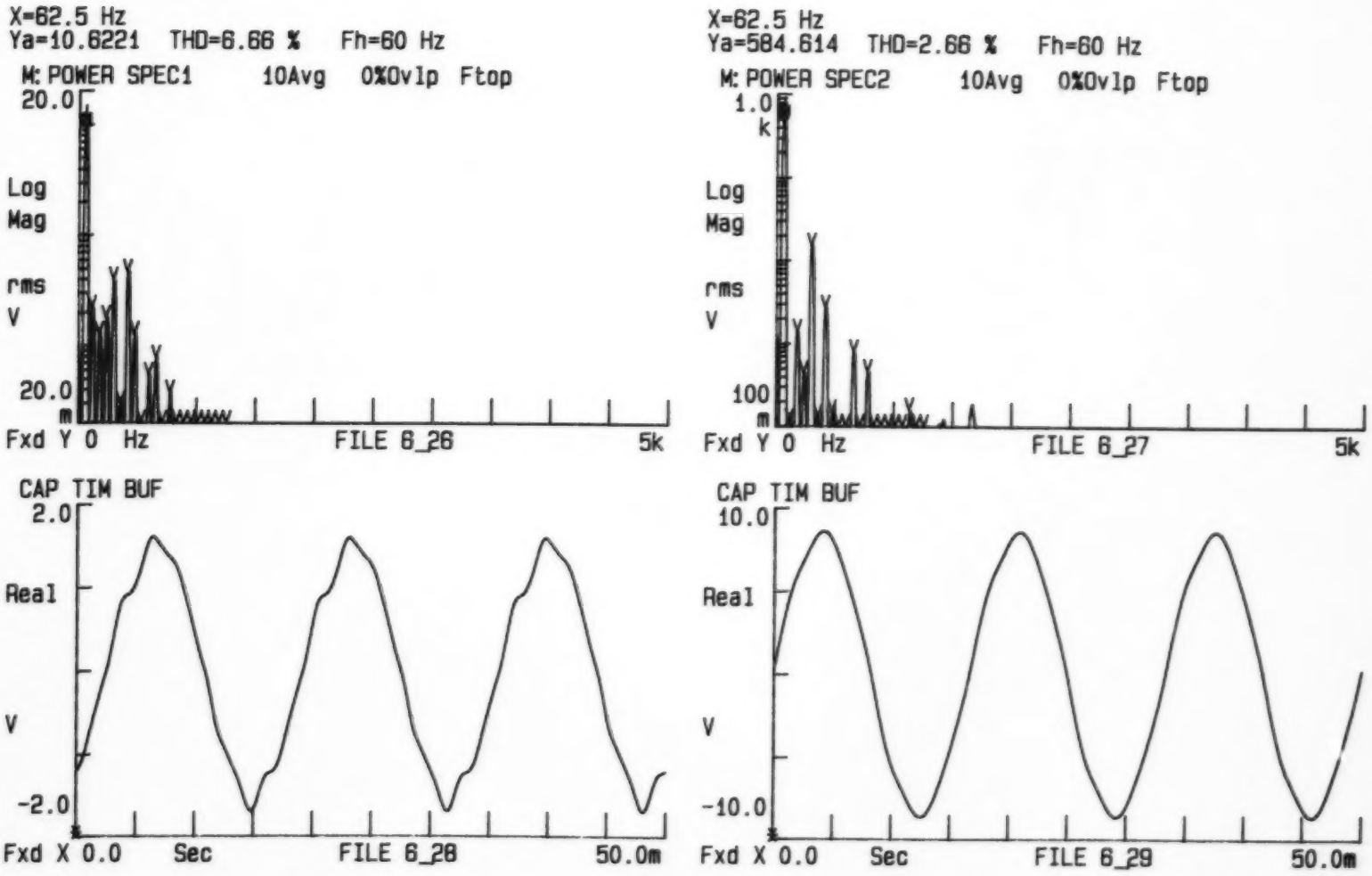

Figure 6 a) ***Battery Charger No. 6, Ferroresonant Type Under Maximum Charging Rate.***

i) ***Top Left - Current Harmonics***
Bottom Left - Current Waveform

$I_{60\ Hz}$ = 10.6 A rms, THD = 6.7%

ii) ***Top Right - Voltage Harmonics***
Bottom Right - Voltage Waveform

$V_{60\ Hz}$ = 584.6 V rms, THD = 2.7%

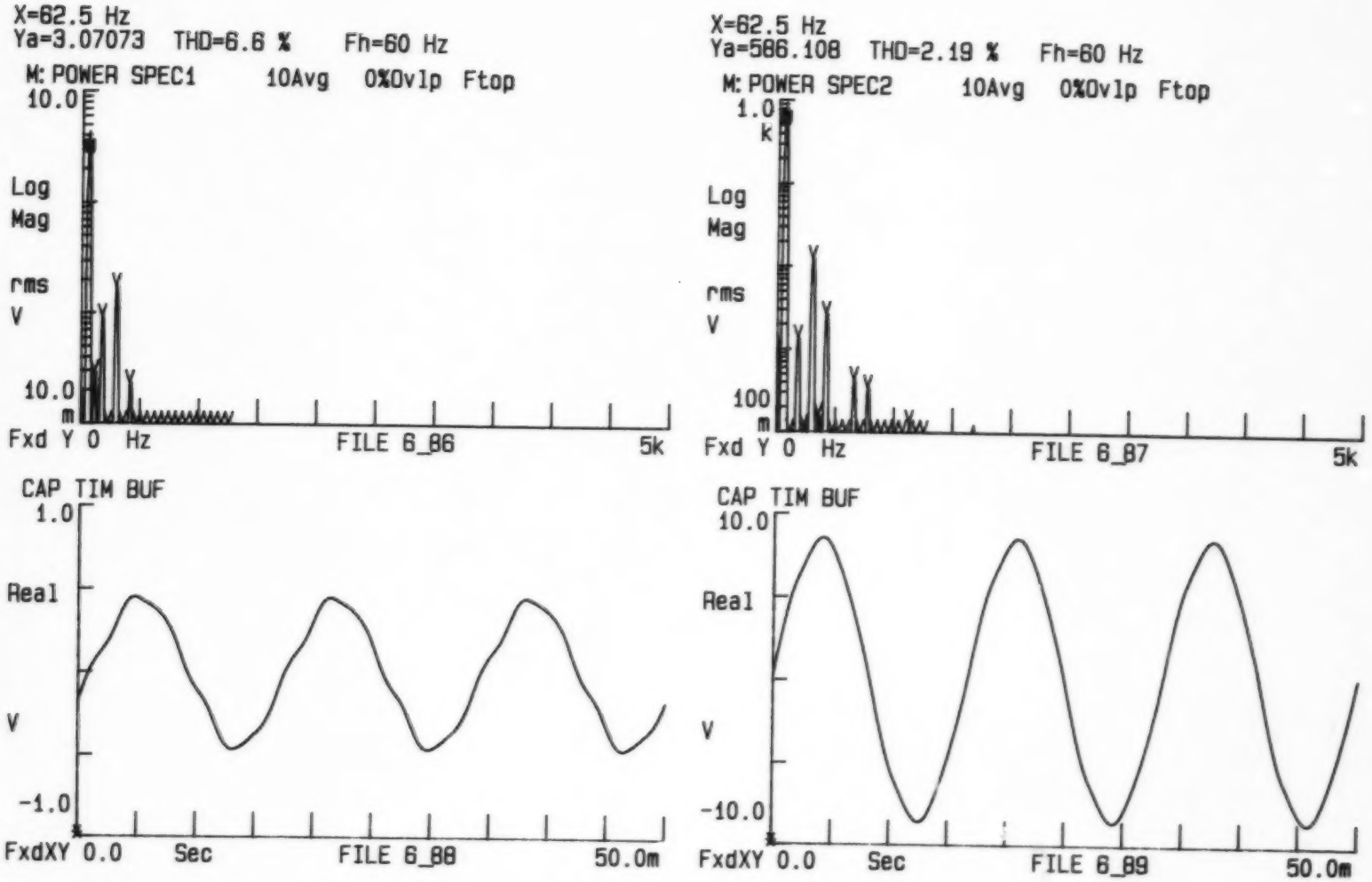

Figure 6 b) ***Battery Charger No. 6, Ferroresonant Type Under Minimum Charging Rate.***

i) ***Top Left - Current Harmonics***
Bottom Left - Current Waveform

$I_{60\ Hz}$ = 3.1 A rms, THD = 6.6%

ii) ***Top Right - Voltage Harmonics***
Bottom Right - Voltage Waveform

$V_{60\ Hz}$ = 586.1 V rms, THD = 2.2%

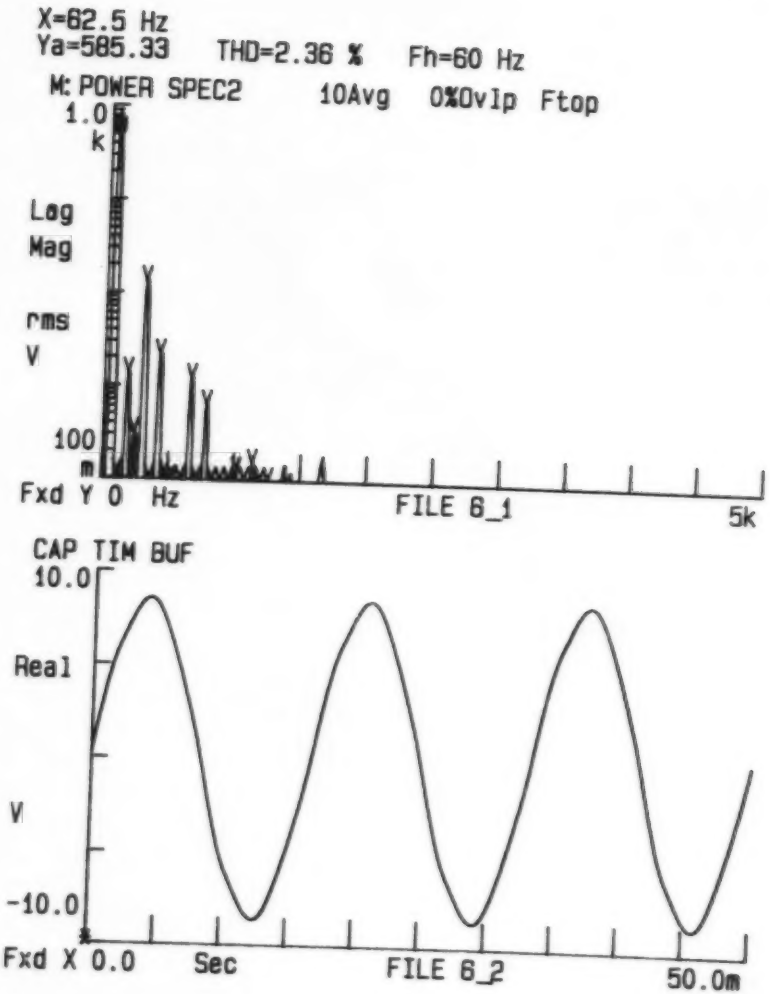

Figure 6 c) ***Battery Charger No. 6, Ferroresonant Type Ambient Voltage Conditions.***

Top - Voltage Harmonics
Bottom - Voltage Waveform

$V_{60\ Hz}$ = 585.3 V rms, THD = 2.4%

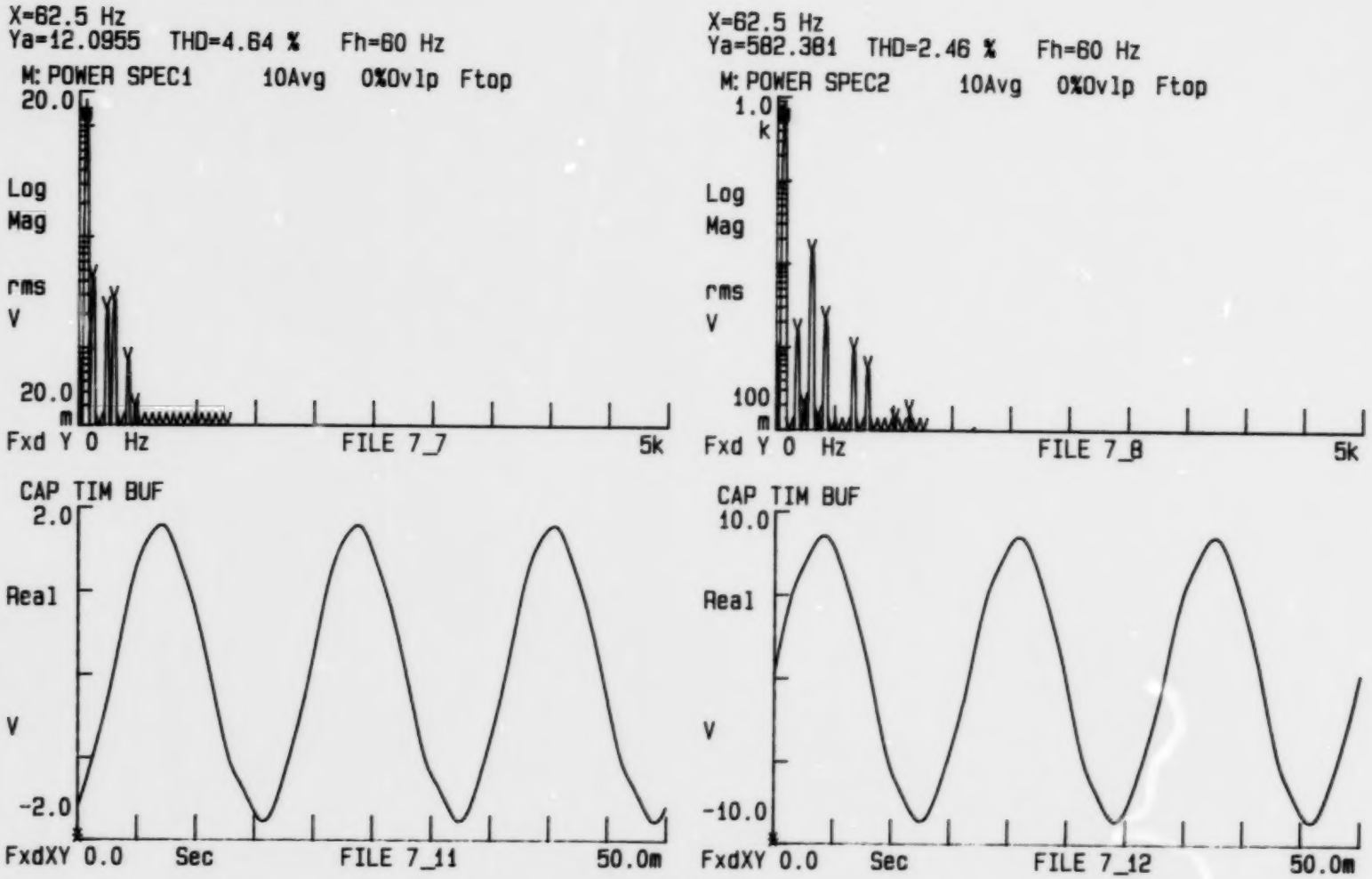

Figure 7 a) ***Battery Charger No. 7, Ferroresonant Type Under Maximum Charging Rate.***

i) ***Top Left - Current Harmonics***
Bottom Left - Current Waveform

$I_{60\ Hz}$ = 12.1 A rms, THD = 4.6%

ii) ***Top Right - Voltage Harmonics***
Bottom Right - Voltage Waveform

$V_{60\ Hz}$ = 582.4 V rms, THD = 2.5%

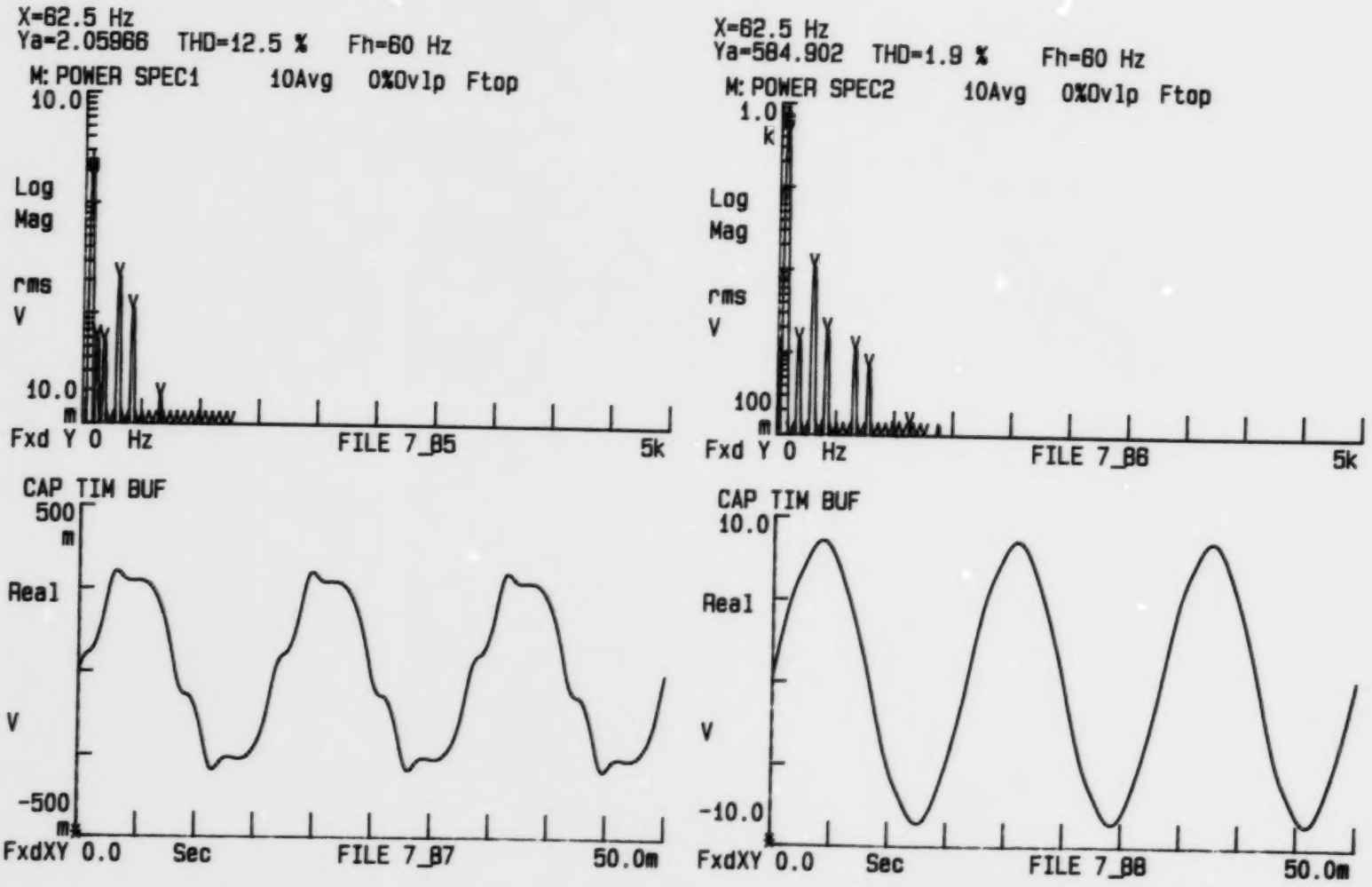

Figure 7 b) ***Battery Charger No. 7, Ferroresonant Type Under Minimum Charging Rate.***

i) ***Top Left - Current Harmonics***
Bottom Left - Current Waveform

$I_{60\ Hz}$ = 2.1 A rms, THD = 12.5%

ii) ***Top Right - Voltage Harmonics***
Bottom Right - Voltage Waveform

$V_{60\ Hz}$ = 584.9 V rms, THD = 1.9%

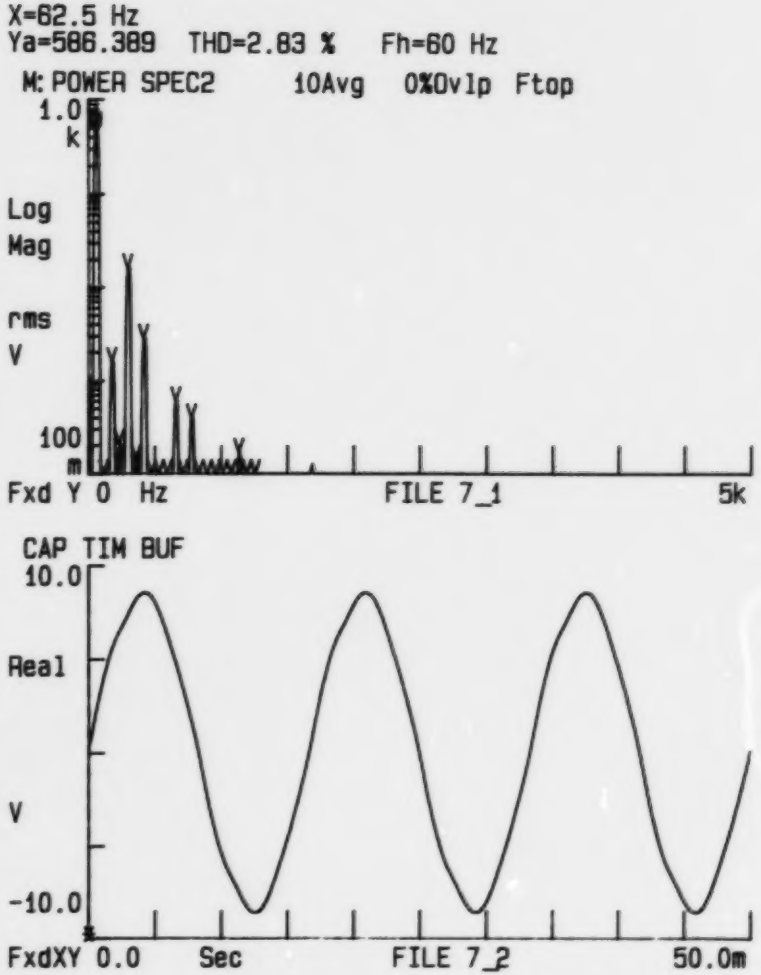

Figure 7 c) ***Battery Charger No. 7, Ferroresonant Type Ambient Voltage Conditions.***

Top - Voltage Harmonics
Bottom - Voltage Waveform

$V_{60\ Hz}$ = 586.4 V rms, THD = 2.8%

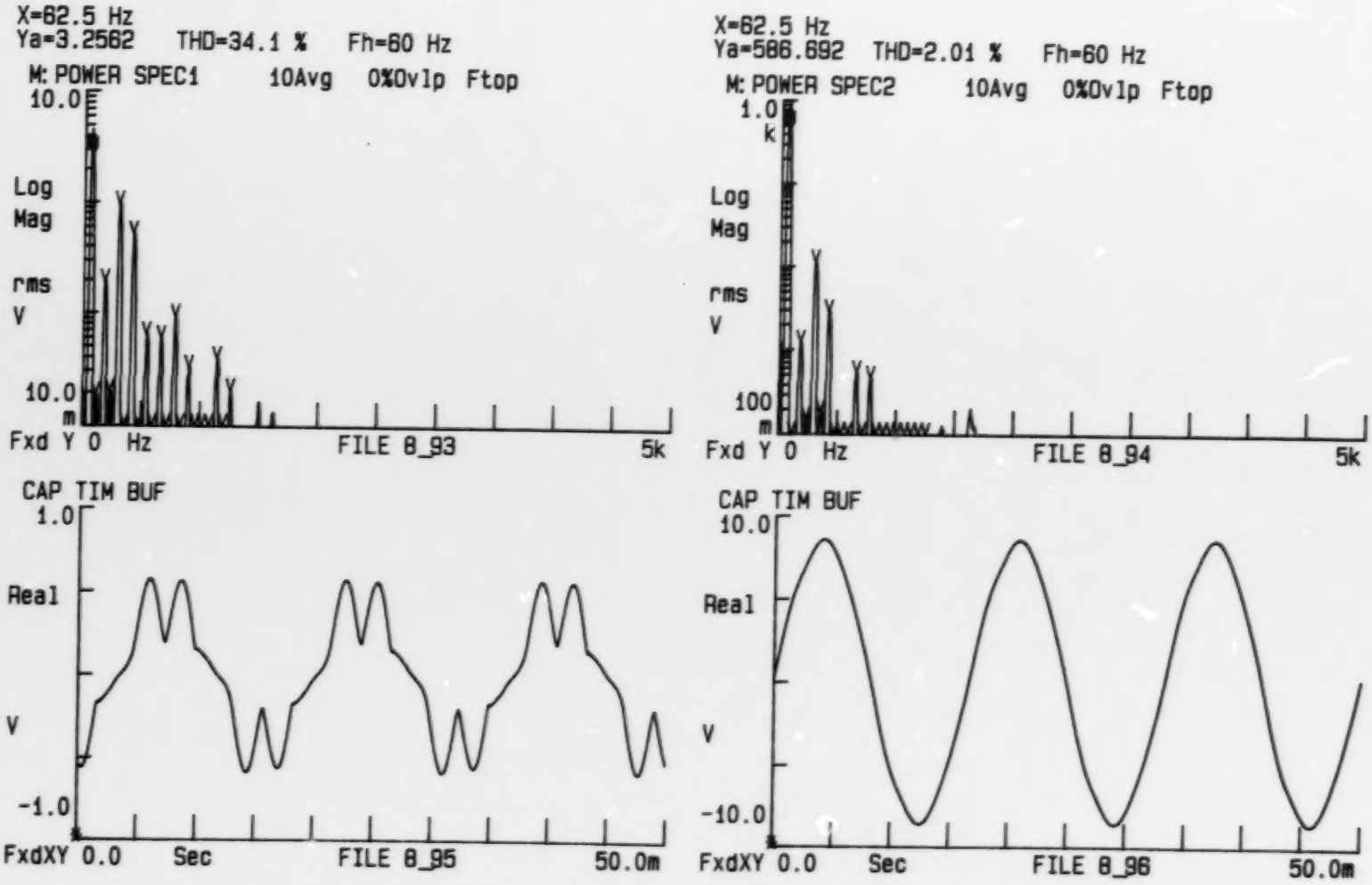

Figure 8 b) ***Battery Charger No. 8, Magnetic Amplifier Under Minimum Charging Rate.***

i) ***Top Left - Current Harmonics***
Bottom Left - Current Waveform

$I_{60\,Hz}$ = 3.3 A rms, THD = 34.1%

ii) ***Top Right - Voltage Harmonics***
Bottom Right - Voltage Waveform

$V_{60\,Hz}$ = 586.7 V rms, THD = 2.0%

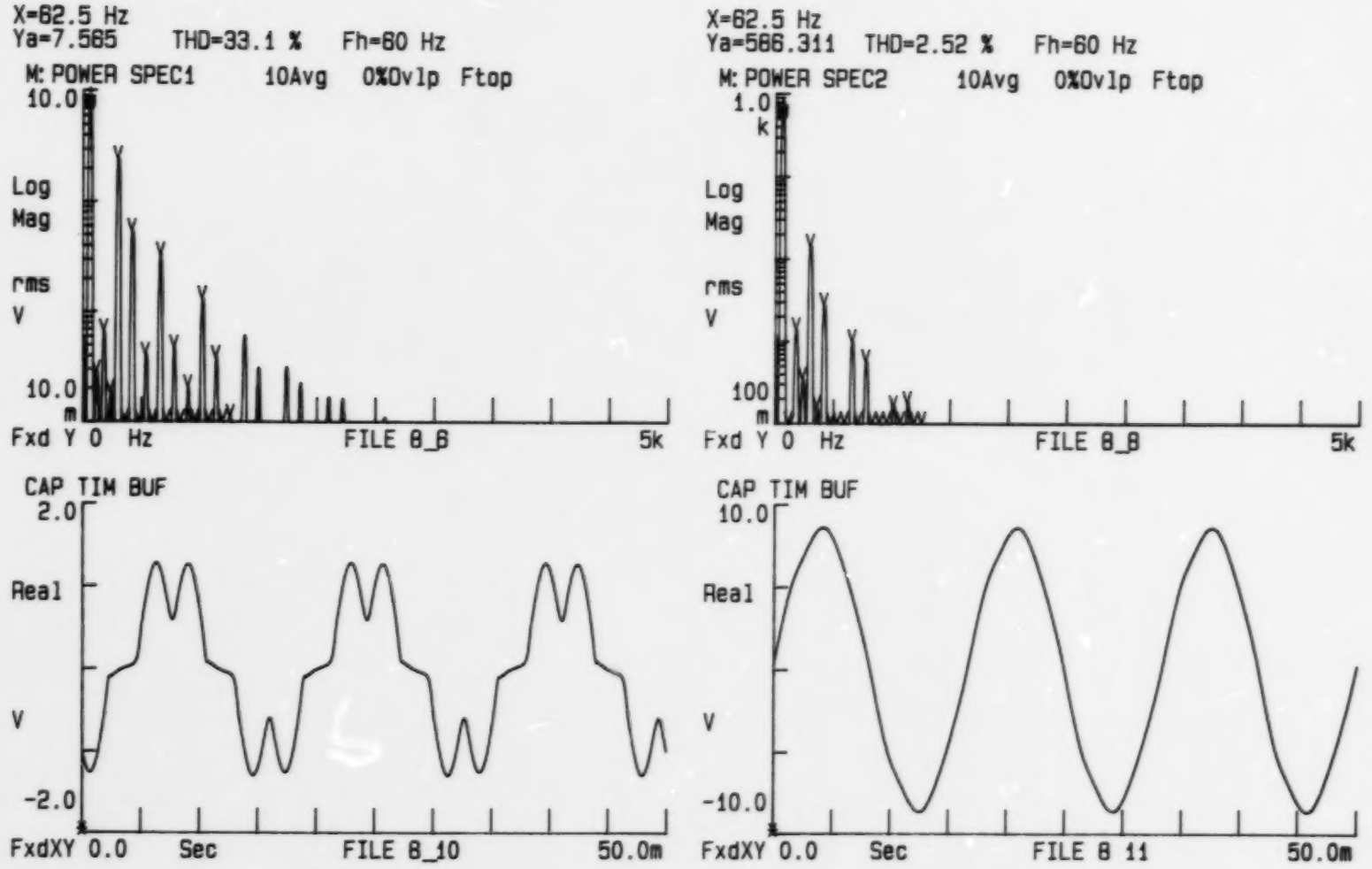

Figure 8 a) ***Battery Charger No. 8, Magnetic Amplifier Under Maximum Charging Rate.***

i) ***Top Left - Current Harmonics***
Bottom Left - Current Waveform

$I_{60\ Hz}$ = 7.6 A rms, THD = 33.1%

ii) ***Top Right - Voltage Harmonics***
Bottom Right - Voltage Waveform

$V_{60\ Hz}$ = 586.3 V rms, THD = 2.5%

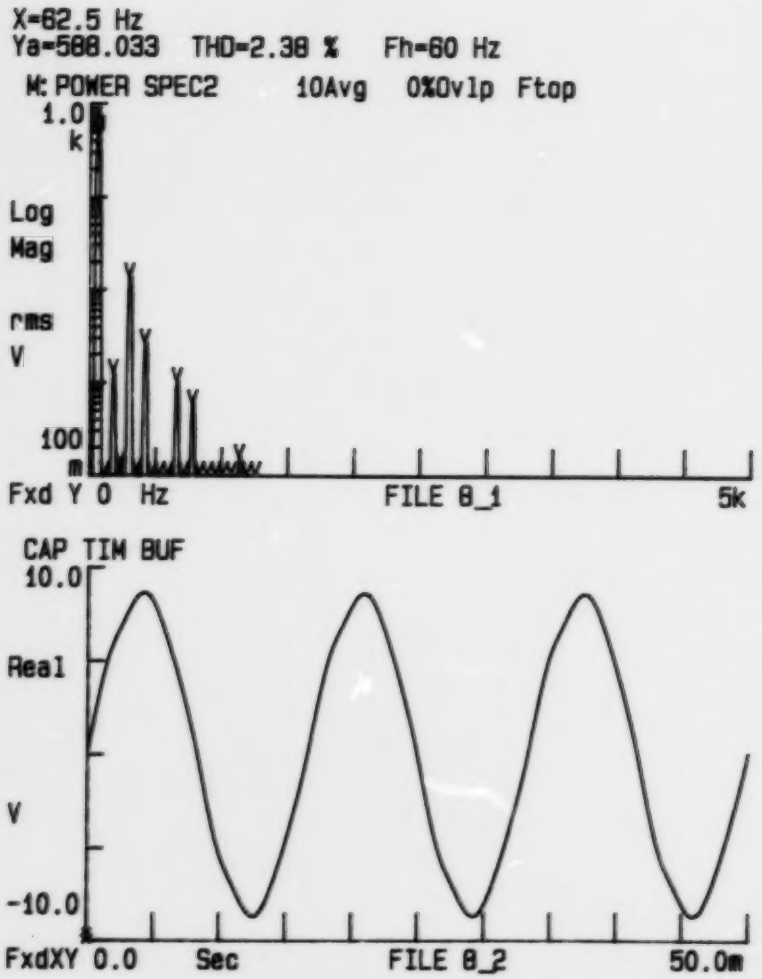

Figure 8 c) ***Battery Charger No. 8, Magnetic Amplifier Ambient Voltage Conditions.***

Top - Voltage Harmonics
Bottom - Voltage Waveform

$V_{60\ Hz}$ = 588.0 Vrms, THD = 2.4%

Table 5 a) ***Battery Charger No. 5, Magnetic Amplifier Under Maximum Charging Rate.***

BATTERY CHARGER #5

Condition: Max charge rate
Filename: 5_11
Ir : Fund 8.29A rms Composite 8.52A rms
THD=23.7 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	141
2	120	.23	153
3	180	.34	-161
4	240	.17	-72
5	300	22.93	172
6	360	.14	-163
7	420	5.00	123
8	480	.04	22
9	540	.44	-50
10	600	.12	-49
11	660	2.50	13
12	720	.05	11
13	780	1.13	-111
14	840	.04	90
15	900	.08	153
16	960	.05	90
17	1020	1.55	173
18	1080	.03	145
19	1140	.68	-10
20	1200	.01	-141
21	1260	.09	-55

BATTERY CHARGER #5

Condition: Max charge rate
Filename: 5_12
Vr-w : Fund 587.72V rms Composite 587.86V rms
THD= 2.2 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	-155
2	120	.01	-80
3	180	.21	135
4	240	.03	76
5	300	2.10	-95
6	360	.01	31
7	420	.44	54
8	480	0.00	0
9	540	.01	-134
10	600	0.00	0
11	660	.11	-108
12	720	.01	61
13	780	.07	120
14	840	0.00	0
15	900	.01	-13
16	960	0.00	0
17	1020	.02	68
18	1080	0.00	0
19	1140	.02	-19
20	1200	.01	103
21	1260	.01	108

Table 5 b) ***Battery Charger No. 5, Magnetic Amplifier Under Minimum Charging Rate.***

BATTERY CHARGER #5

Condition: Min charge rate
Filename: 5_83
Ir : Fund 3.37A rms Composite 3.41A rms
THD=15.7 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	145
2	120	.29	94
3	180	3.67	37
4	240	.19	-80
5	300	8.82	-114
6	360	.15	178
7	420	10.69	-171
8	480	.13	159
9	540	.53	-100
10	600	.16	-11
11	660	6.11	176
12	720	.03	35
13	780	1.45	29
14	840	.02	-154
15	900	.21	176
16	960	.04	43
17	1020	1.31	44
18	1080	.02	74
19	1140	.34	-77
20	1200	.01	148
21	1260	.22	37

BATTERY CHARGER #5

Condition: Min charge rate
Filename: 5_84
Vr-w : Fund 594.00V rms Composite 594.16V rms
THD= 2.3 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	-155
2	120	.02	-80
3	180	.27	148
4	240	.03	110
5	300	2.24	-91
6	360	.03	-45
7	420	.37	61
8	480	0.00	0
9	540	0.00	0
10	600	.01	141
11	660	.09	-99
12	720	0.00	0
13	780	.08	108
14	840	.01	71
15	900	.01	32
16	960	0.00	0
17	1020	.01	-138
18	1080	0.00	0
19	1140	.02	-19
20	1200	.01	-77
21	1260	.01	-162

Table 5 c) ***Battery Charger No. 5, Magnetic Amplifier Ambient Voltage Conditions.***

BATTERY CHARGER #5

Condition: Ambient
Filename: 5_2
Vr-w : Fund 587.08V rms Composite 587.25V rms
THD= 2.4 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	-155
2	120	.01	-125
3	180	.22	132
4	240	.03	110
5	300	2.29	-108
6	360	0.00	0
7	420	.47	54
8	480	.01	176
9	540	.01	-179
10	600	0.00	0
11	660	.10	-119
12	720	0.00	0
13	780	.08	93
14	840	0.00	0
15	900	.01	-13
16	960	0.00	0
17	1020	.01	132
18	1080	0.00	0
19	1140	.02	-38
20	1200	0.00	0
21	1260	0.00	0

Table 6 a) ***Battery Charger No. 6, Ferroresonant Type Under Maximum Charging Rate.***

BATTERY CHARGER #6

Condition: Max charge rate
Filename: 6_28
Ir : Fund 10.65A rms Composite 10.67A rms
THD= 6.7 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	150
2	120	2.09	-176
3	180	1.19	19
4	240	1.70	145
5	300	3.76	44
6	360	.28	-31
7	420	4.40	22
8	480	1.21	-90
9	540	.17	-132
10	600	.51	-136
11	660	.73	-151
12	720	.02	125
13	780	.36	-70
14	840	.11	62
15	900	.01	167
16	960	.07	46
17	1020	.04	155
18	1080	.01	-133
19	1140	.04	18
20	1200	.03	-149
21	1260	.01	18

BATTERY CHARGER #6

Condition: Max charge rate
Filename: 6_29
Vr-w : Fund 589.45V rms Composite 589.66V rms
THD= 2.7 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	-154
2	120	.02	-107
3	180	.24	140
4	240	.08	110
5	300	2.60	-101
6	360	.02	-59
7	420	.50	42
8	480	.02	176
9	540	.01	-179
10	600	0.00	0
11	660	.09	-104
12	720	.01	-119
13	780	.06	87
14	840	0.00	0
15	900	.01	-13
16	960	0.00	0
17	1020	.01	42
18	1080	0.00	0
19	1140	.03	-49
20	1200	0.00	0
21	1260	0.00	0

Table 6 b) ***Battery Charger No. 6, Ferroresonant Type Under Minimum Charging Rate.***

BATTERY CHARGER #6

Condition: Min charge rate
Filename: 6_88
Ir : Fund 3.07A rms Composite 3.08A rms
THD= 6.6 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	180
2	120	.97	-152
3	180	3.03	172
4	240	.11	-89
5	300	5.73	-85
6	360	.15	179
7	420	.76	45
8	480	.22	116
9	540	.21	-9
10	600	.08	131
11	660	.08	-139
12	720	.02	61
13	780	.11	11
14	840	.03	71
15	900	.05	-32
16	960	.01	82
17	1020	.02	-138
18	1080	.01	2
19	1140	.01	-38
20	1200	.01	103
21	1260	.02	-9

BATTERY CHARGER #6

Condition: Min charge rate
Filename: 6_89
Vr-w : Fund 588.55V rms Composite 588.69V rms
THD= 2.1 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	-154
2	120	.01	-125
3	180	.24	133
4	240	.02	129
5	300	2.08	-96
6	360	.02	-86
7	420	.43	35
8	480	.01	131
9	540	.01	-134
10	600	0.00	0
11	660	.10	-88
12	720	0.00	0
13	780	.08	96
14	840	0.00	0
15	900	.02	-13
16	960	0.00	0
17	1020	.02	60
18	1080	.01	-178
19	1140	.02	-38
20	1200	0.00	0
21	1260	.01	108

Table 6 c) ***Battery Charger No. 6, Ferroresonant Type Ambient Voltage Conditions.***

BATTERY CHARGER #6

Condition: Ambient
Filename: 6_2
Vr-w : Fund 589.46V rms Composite 589.61V rms
THD= 2.3 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	-154
2	120	.01	-80
3	180	.23	134
4	240	.04	132
5	300	2.25	-102
6	360	.01	-104
7	420	.38	55
8	480	.02	-166
9	540	.01	-134
10	600	.01	51
11	660	.15	-97
12	720	0.00	0
13	780	.10	102
14	840	0.00	0
15	900	.02	-40
16	960	0.00	0
17	1020	.01	87
18	1080	0.00	0
19	1140	.02	-38
20	1200	0.00	0
21	1260	.01	-162

Table 7 a) ***Battery Charger No. 7, Ferroresonant Type Under Maximum Charging Rate.***

BATTERY CHARGER #7

Condition: Max charge rate
Filename: 7_11
Ir : Fund 12.10A rms Composite 12.11A rms
THD= 4.6 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	141
2	120	3.54	-17
3	180	.06	98
4	240	1.85	-57
5	300	2.26	-79
6	360	.07	-162
7	420	.64	-120
8	480	.24	-33
9	540	.03	-108
10	600	.04	-151
11	660	.08	15
12	720	.01	-29
13	780	.09	9
14	840	.02	26
15	900	.01	-103
16	960	.02	-143
17	1020	.03	-169
18	1080	0.00	0
19	1140	.02	161
20	1200	.02	76
21	1260	0.00	0

BATTERY CHARGER #7

Condition: Max charge rate
Filename: 7_12
Vr-w : Fund 586.83V rms Composite 587.04V rms
THD= 2.7 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	-154
2	120	.01	-80
3	180	.27	146
4	240	.04	-160
5	300	2.62	-102
6	360	.04	-59
7	420	.45	40
8	480	.01	131
9	540	.02	-134
10	600	.01	-129
11	660	.10	-93
12	720	.01	-119
13	780	.06	102
14	840	0.00	0
15	900	.02	-40
16	960	0.00	0
17	1020	.02	-48
18	1080	0.00	0
19	1140	.02	-64
20	1200	0.00	0
21	1260	0.00	0

Table 7 b) ***Battery Charger No. 7, Ferroresonant Type Under Minimum Charging Rate.***

BATTERY CHARGER #7

Condition: Min charge rate
Filename: 7_87
Ir : Fund 2.06A rms Composite 2.07A rms
THD=12.4 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	-163
2	120	2.90	41
3	180	2.70	60
4	240	.43	-36
5	300	10.33	38
6	360	.17	175
7	420	5.43	-168
8	480	.07	-168
9	540	.30	-11
10	600	.08	136
11	660	.89	-25
12	720	.02	5
13	780	.42	133
14	840	.02	8
15	900	.04	-82
16	960	.01	-98
17	1020	.08	-8
18	1080	0.00	0
19	1140	.08	-173
20	1200	.01	-33
21	1260	.01	-27

BATTERY CHARGER #7

Condition: Min charge rate
Filename: 7_88
Vr-w : Fund 588.79V rms Composite 588.91V rms
THD= 2.0 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	-155
2	120	.01	-80
3	180	.24	135
4	240	.04	132
5	300	1.95	-100
6	360	.03	-73
7	420	.36	30
8	480	0.00	0
9	540	0.00	0
10	600	0.00	0
11	660	.15	-115
12	720	0.00	0
13	780	.09	80
14	840	.01	-19
15	900	.02	-13
16	960	.01	-98
17	1020	.02	23
18	1080	0.00	0
19	1140	.02	-65
20	1200	.01	102
21	1260	.01	108

Table 7 c) ***Battery Charger No. 7, Ferroresonant Type Ambient Voltage Conditions.***

BATTERY CHARGER #7

Condition: Ambient
Filename: 7_2
Vr-w : Fund 586.59V rms Composite 586.80V rms
THD= 2.7 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	-155
2	120	.01	-125
3	180	.27	135
4	240	.02	-160
5	300	2.61	-108
6	360	.01	-104
7	420	.43	32
8	480	.02	-166
9	540	.01	-89
10	600	0.00	0
11	660	.21	-160
12	720	0.00	0
13	780	.11	38
14	840	0.00	0
15	900	.03	-47
16	960	0.00	0
17	1020	.02	15
18	1080	0.00	0
19	1140	.03	-97
20	1200	0.00	0
21	1260	.01	63

Table 8 a) ***Battery Charger No. 8, Magnetic Amplifier Under Maximum Charging Rate.***

BATTERY CHARGER #8

Condition: Max charge rate
Filename: 8_10
Ir : Fund 7.57A rms Composite 7.98A rms
THD=33.0 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	129
2	120	.38	-170
3	180	.90	127
4	240	.22	46
5	300	31.92	98
6	360	.09	-131
7	420	7.07	-10
8	480	.03	117
9	540	.55	150
10	600	.01	-129
11	660	4.32	147
12	720	.01	106
13	780	.61	-42
14	840	.04	-109
15	900	.28	164
16	960	.01	-8
17	1020	1.73	-168
18	1080	.01	-178
19	1140	.50	-57
20	1200	.03	-63
21	1260	.15	-180

BATTERY CHARGER #8

Condition: Max charge rate
Filename: 8_11
Vr-w : Fund 590.28V rms Composite 590.46V rms
THD= 2.5 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	-154
2	120	.01	-80
3	180	.24	148
4	240	.04	141
5	300	2.41	-99
6	360	.01	-59
7	420	.45	37
8	480	.02	-166
9	540	.01	-44
10	600	0.00	0
11	660	.11	-87
12	720	0.00	0
13	780	.07	107
14	840	0.00	0
15	900	.01	-13
16	960	0.00	0
17	1020	.02	42
18	1080	0.00	0
19	1140	.03	-83
20	1200	0.00	0
21	1260	.01	153

Table 8 b) ***Battery Charger No. 8, Magnetic Amplifier Under Minimum Charging Rate.***

BATTERY CHARGER #8

Condition: Min charge rate
Filename: 8_95
Ir : Fund 3.25A rms Composite 3.44A rms
THD=34.0 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	132
2	120	.63	-138
3	180	5.80	164
4	240	.65	73
5	300	29.27	133
6	360	.18	-101
7	420	15.74	41
8	480	.10	33
9	540	1.94	-116
10	600	.15	154
11	660	1.80	-111
12	720	.07	12
13	780	2.80	135
14	840	.05	-169
15	900	.99	-9
16	960	.07	-81
17	1020	.13	27
18	1080	.06	106
19	1140	1.18	-124
20	1200	.03	-89
21	1260	.65	91

BATTERY CHARGER #8

Condition: Min charge rate
Filename: 8_96
Vr-w : Fund 589.79V rms Composite 589.90V rms
THD= 2.0 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	-155
2	120	.01	-125
3	180	.21	130
4	240	.05	94
5	300	1.93	-97
6	360	.03	-123
7	420	.49	32
8	480	.02	-166
9	540	.02	109
10	600	.01	141
11	660	.11	-128
12	720	0.00	0
13	780	.08	78
14	840	0.00	0
15	900	.01	-58
16	960	0.00	0
17	1020	.02	150
18	1080	.01	-88
19	1140	.02	-19
20	1200	0.00	0
21	1260	0.00	0

Table 8 c) ***Battery Charger No. 8, Magnetic Amplifier Ambient Voltage Conditions.***

BATTERY CHARGER #8

Condition: Ambient
Filename: 8_2
Vr-w : Fund 591.79V rms Composite 591.99V rms
THD= 2.6 %

Harmonic number	Frequency Hz	Magnitude % of fund.	Phase degrees
1	60	100.00	-155
2	120	.01	-35
3	180	.24	145
4	240	.02	155
5	300	2.57	-107
6	360	.03	-59
7	420	.55	29
8	480	.01	131
9	540	.01	-134
10	600	0.00	0
11	660	.06	-110
12	720	0.00	0
13	780	.04	88
14	840	.01	-19
15	900	.01	-13
16	960	0.00	0
17	1020	.02	-48
18	1080	0.00	0
19	1140	.02	-101
20	1200	0.00	0
21	1260	.01	153